Karen Adolph explains how we develop our ability to move through the world

How do babies' bodies and their environment teach them to move—and how can robots benefit from these insights?

25 October 2024 | by PAUL MIDDLEBROOKS

This transcript has been lightly edited for clarity; it may contain errors due to the transcription process.

[music]

Karen Adolph
My diabolical scheme is to use simulated robots to understand behavior, but their diabolical scheme is to use developing behavior to build better robots. We saw children do things in hammering the peg that no one would ever have imagined that a child would do. We actually, right now, we as a field because if Karen Adolph can do it, anyone can do it.

Paul Middlebrooks
Oh, come on.

Karen Adolph
We have all the tools and technology to do the whole enchilada.

Paul Middlebrooks
This is *Brain Inspired*, powered by *The Transmitter*. Hey, everyone. I'm Paul. I'm a neuroscience researcher at Carnegie Mellon University. I also have children. I was witness early on to their tiny bodies fumbling about the world as they learned to crawl and then walk, and then run, and jump. I haven't seen nearly as many babies do that as my guest today, Karen Adolph.

Karen runs the Infant Action Lab at New York University, NYU, where she studies how our motor behaviors develop from infancy onward. We discuss how observing babies at different stages of development illuminates how movement and cognition develop in humans, how variability and embodiment are key to that development, and the importance of studying behavior in real-world settings as opposed to more restricted laboratory settings. We also explore how these principles, together with simulations, can inspire advances in intelligent robots.

Karen has a long-standing interest in ecological psychology, which we have discussed multiple times over the past month or two on this podcast. She shares some stories of her time studying under Eleanor Gibson, the developmental ecological psychologist, who was a colleague of the well-known ecological psychologist, the-- what would you say-- originator, perhaps, of ecological psychology, James Gibson. She talks about her time with Eleanor and some of her other mentors.

Finally, we get a surprise visit from Karen's partner, Mark Bloomberg, with whom she co-authored an opinion piece arguing that "motor cortex doesn't actually start off with a motor function, oddly enough, but instead processes sensory information during the first period of animals' lives". Okay. I'll link to the papers associated with the topics I just mentioned and which we discuss in this episode at braininspired.co/podcast/197. Those church bells in the background tell me that it's time to quit this introduction and get into the episode.

Thank you to all my Patreon supporters, learn more at braininspired.co how to do that, and join our Discord community, and even influence who comes on this podcast. Thank you as always to *The Transmitter* for their awesome support of this show. All right, here's Karen.

[music]

Paul Middlebrooks
Karen, you're busy. You've been busy for a long time. Do you feel just overwhelmed all the time?

Karen Adolph
No, I have the best job in the world. I really do.

Paul Middlebrooks
You're just talking like--

Karen Adolph
I really do. I have the best job in the world.

Paul Middlebrooks
Is that right?

Karen Adolph
Yes.

Paul Middlebrooks
Why humans?

Karen Adolph
Why human what? Why do I study human behavior?

Paul Middlebrooks
Yes. As opposed to some other animal model?

Karen Adolph
Why? Because you have to know your organism. I worked my way through college working with three and four-year-olds, and I really know young children and babies. I'm about to do a piglet study in September.

Paul Middlebrooks
Uh-oh.

Karen Adolph
Pigs at the edge of a drop-offs, and we got some chick stuff on the horizon. It could be any animal. Pretty much anything I've learned about any animal, they all produce amazing, beautiful behaviors that learn and develop. It could have been any animal. It's just I have a better feeling for the human animal.

Paul Middlebrooks
Has it always been development, in particular, that you've been interested in, and the behavior?

Karen Adolph
Yes, I'll tell you why. I was one of those children that was your parent's worst nightmare. Well, among them [chuckles]. I went to four colleges. By the time I was at Sarah Lawrence, my fourth,-

Paul Middlebrooks
Wow.

Karen Adolph
-I was paying my own way. It's so convoluted, but I ended up at Sarah Lawrence because I wanted to study printmaking with this famous, amazing Japanese woodcut printmaker, Ansei Uchima. He told me that everything I had done to date at that point, I believe him, he was right, was self-indulgent, drivel, and that I needed to become a better draftsman. While everyone else in the class is doing other things, he would bring me things to draw. They were usually some branch, some twig, sprig of something that he plucked on his way into the studio, and he would put it down and say, "Draw it."

Then I always came up short, and he said, "You need to just still yourself and really look so that you can understand how it grows." I got really pretty good at doing that. Then through another convoluted story, I ended up doing my doctoral work in part with Eleanor Gibson. I consider her my primary advisor.

Paul Middlebrooks
I was about to ask you about that.

Karen Adolph
Her main advice was actually the same, but only about behavior. Just shut up, sit still, open your mind, and let the behavior speak to you.

Paul Middlebrooks
She wasn't telling you that your work was drivel?

Karen Adolph
Oh, she sure did. [laughs]

Paul Middlebrooks
Did she? How?

Karen Adolph
She had these things. She would say that our work was fine, just fine, or bunk. It drove me crazy because I never knew whether fine was better than just fine or just fine was better than fine. I'd say, "Jackie, Jackie, which one's better? Am I striving for just fine or fine?" She said, "I don't care." I'll tell you a funny story. I think I was in my second faculty job. I moved to NYU. Then that means I was tenured. I was doing fine. I was doing just fine or fine. I don't know.

Paul Middlebrooks
[chuckles] Yes. One of those.

Karen Adolph
One of those. It was the olden days, so we had answering machines and the light was flashing. I pressed Play, and it was Eleanor Gibson saying, "Karen, dear, thank you so much for sending me the chapter or article, whatever you wrote, I think it's terrific. It was so fun to read, and terrific, terrific." She said a few other things. Then I press the thing again. "Karen, dear, I took another look at your article, and while it's fine," or whatever, [laughs] "There's a few things we need to discuss."

Paul Middlebrooks
Just fine or fine?

Karen Adolph
Literally, there was a third message-

Paul Middlebrooks
Oh, my God [laughs].

Karen Adolph
-and she said, "We really need to talk before you send this."

Paul Middlebrooks
That's funny.

Karen Adolph
I don't know that I was a disappointment to her. I think she loved me. That I know. I don't think she considered me her best student. In the end, I might turn out to have been her best student. We'll see.

Paul Middlebrooks
Well, how did you-- did that kind of criticism-- Because some people would wilt under that kind of criticism earlier in their careers.

Karen Adolph
Oh, I'm not a wilter, my friend. I'm not a wilter. You know what? When I wrote my dissertation, my three advisors were Ulric Neisser, the father of cognitive psychology, Eleanor Gibson [laughs], Jackie Gibson, whatever, the mother of behavioral-- whatever, and Esther Thelen, who invented dynamic systems. All three hated it, but for different reasons. Eleanor Gibson said, "Karen, I had to stop reading it at the title. It just won't do. I couldn't read past the title."

Paul Middlebrooks
Wow.

Karen Adolph
That was pretty bad. With Neisser, it was the way I presented the results. Esther Thelen kept saying, "But I've written things with you. What's wrong? Did you write this? Did you write-- Because I've written things with you. What was that? Did you really write that? Why would you? Karen, why would you write that?"

Paul Middlebrooks
Wow.

Karen Adolph
With the olden days, we had the five-inch floppy disk. I just took the whole thing and all the paper, threw it in the trash, started over, said, "Jackie, how about this title?" "Okay, dear, you can continue." "Esther, I'm going to show it to you section by section." She gave me the thumbs up and I got to the results, and Dick Neisser.

Paul Middlebrooks
That's intense beneficial training in the long run.

Karen Adolph
I'm not a wilter.

Paul Middlebrooks
No.

Karen Adolph
I'm just a get back on each going person.

Paul Middlebrooks
I haven't published these episodes yet, but I have a few episodes specifically on ecological psychology with a few people. Did your interest in ecological psychology begin with Eleanor?

Karen Adolph
No. There, I was at Sarah Lawrence working in The Early Childhood Center, paying my way through college. I took a class on perception because I thought it would help me to understand-- that's the thing that although-- Sarah Lawrence had just gone co-ed and there's five men, all-gay, dancers, whatever, and all these women, we all look the same, hair to our waist, black clothes wafting through the campus.

Paul Middlebrooks
What year is this? What decade is this?

Karen Adolph
The '80s. Meeting in the pub, smoking cigarettes, discussing, how do I know it's a rock, and deep questions like that [laughs]. Wait, what did you ask me?

Paul Middlebrooks
Just about your interest on ecological psychology because Eleanor was--

Karen Adolph
Oh, right. I was taking perception with this guy named Bob Becklin who had been a doctoral student at Cornell since he knew James Gibson very well, and Ulric Neisser was his dissertation advisor. He knew Eleanor Gibson as a by-product. She wasn't on their official faculty then because of nepotism, so it's a whole other amazing story, but he knew the Gibsons. The first semester was a traditional perception class, and it was supposed to be a two-semester, like fall and then spring semester-long class.

I went to him and the end of the fall semester after we'd learned about the chambered eye and the blind spot and all these optical illusions, whatever the hell you teach in traditional perception, I went to him in tears and I said, "Bob, I have to drop your class. I just know this is not how we see. It's just everything about it feels wrong. This is not for me and it's not helping me to-- I wanted to understand how you get light into a painting. It's not helping me to understand my painting. Bye-bye." He said, "Well, all right, before you leave, just read this book over the Christmas break and then see if you still want to drop the class." He gave me James Gibson's, *The Senses Considered as Perceptual Systems*. It was like I found religion.

I copied most of the book into my journals because I had to give the book back. He died in '79, and Eleanor Gibson was still alive. In the end when I decided to do a doctoral program, I wanted to work with her.

Paul Middlebrooks
One of the things I've asked a recent guest about is, Louie Favela is the guest I'm talking about right now. He's written this book that's trying to connect ecological psychology and the neurosciences, which is all well and good. One of the interesting things to me, though, is that, yes, I know Eleanor continued the Gibsonian work, but Gibsonian ecological psychology, it's from one person and it's essentially remained the same over time, correct?

Karen Adolph
I don't think so.

Paul Middlebrooks
No, because James Gibson is always the person mentioned. Just the concepts, the affordances, continuous perception action cycle, direct perception, those have all been core tenants. It's just odd to me that from my perception, and you please correct me, that those core tenants have remained in place. I'm thinking about it in comparison to neuroscience which has had many, many different influences, but ecological psychology all seems to go back to one person. I know Eleanor doesn't get as much credit as she deserves, right?

Karen Adolph
Yes. You're correct and you're wrong in an orthogonal way. They're married, she read everything he wrote. They published only two things together, and she has publications spanning 70-something years. She was not his partner, and she was not his muse. She was not anything, she was just her own separate person. I never met the man, I only heard about him through her and I read his stuff. He was more interested in epistemological questions. She's really like, shut up, look at the behaviors and let the data speak to you, that was her.

She started as a comparative psychologist and she would have been studying non-human primates if they'd let her do that at Yale and she ended starting out in the rat lab. Some of James Gibson's ideas are now so enmeshed into the literature that people don't even know that it's him, like optic flow. What's really behind that is, you can only understand a process, which is the thing that takes place over time, if you study things that take place over time. All his notions are really these time-based notions about patterns over time, not stopping time in some fictional way like as if it's a photograph. It's continuous.

Some of his ideas, like affordance, are also out there in the literature but in a much sloppier way. When I talk with young roboticists, for example, there's a generation that I just get free revering from them because, "You know Eleanor Gibson?" They only know the term affordance, they have no idea what they're saying, where it came from, and mostly it's meaningless the way they're saying it.

Paul Middlebrooks
Because it's gotten too watered down?

Karen Adolph
It just could mean anything, it's like a helping verb.

Paul Middlebrooks
What does it mean?

Karen Adolph
Well, I think I know what James Gibson thought it means, I think I know what Eleanor Gibson thought it means, and then I think I know what I think it means. Those are the three different things.

Paul Middlebrooks
Wow. See, that's a problem, isn't it?

Karen Adolph
Why?

Paul Middlebrooks
The neuroscientists, for example, I'm a neuroscientist and we're famously bad at using words that we all mean different things by them, like the word representation, it has a thousand different meanings. What happens is people are just talking past each other all the time. I thought that that would not be the case in ecological psychology because, I know this is not fair, but it all originates in this very narrowly-defined way. I know that James Gibson changed notions of things over time as well.

Karen Adolph
I would say, sure, I'm an ecological psychologist, but I'm just myself, and if anything, I'm first and foremost a developmental scientist. It's not in conflict with ecological psychology, and the pre-theoretical assumptions, all come from there, something like direct perception. I don't care. The only things I'm committed to I think are absolutely facts and anyone who's not committed to those things is an idiot. We live in real-time, that's the way it happens, and if you want to understand the process, you have to understand how change happens over time, the end, it's a fact.

Affordance, to my mind, is a fact. It's the fit between a set of characteristics in the environment, a set of characteristics in a particular animal that make a particular action possible or not, or possible with some probability. That's a fact. I don't think anyone who thinks about it would argue with that, whether people can perceive affordances for action and how they perceive it, that's still up in the air, and I don't know the answer to that. Probably, we have to perceive affordances because otherwise, I don't see how any animal can get around and-

Paul Middlebrooks
Fit through the hole.

Karen Adolph
-be like a functional animal in an environment. Affordances are a fact. Define the way I've said it. If you want to say an afford-- like the Zoom call affords learning for listeners, you've not said anything. If you want to say, to perform a motor action, stuff has to be true about the environment, stuff has to be true about the animal, and they have to merge in some way, that's a fact. That's just biomechanics, done.

Paul Middlebrooks
Something like the term "mind", right? Neuroscientists think, a lot of us think that the mind is what brains do. An ecological psychologist thinks

that mind is more relational. Not located in brain so much as the brain-body environment system. What is your conception of mind? Or is this another thing that doesn't matter?

Karen Adolph
I don't think about it like that. I think about processes, like thinking and remembering and hoping and planning and believing and desiring and whatever. Sure. People and human babies and lots of animals do lots of those kinds of things. Those are processes. They are processes that have to do with all the body parts. Brain, but also eyes and feet and skin and whatever, and other people in the environment and all the rest of it.

Paul Middlebrooks
You are pro embodiment, for sure.

Karen Adolph
I think there's a lot of ease, I wrote a paper with a lot of ease before I realized that other people were also into that. Of course, behavior is embodied. How else could it happen? Of course, it's also embedded in the environment. Where else could it happen? There's always an environment. It's also enculturated because at least in people and in many kinds of animals because there's other creatures around that have minimally affected the environment, but also influence behaviors. It's also enabling so that one thing can lead to another thing. We can affect change on our environment, the environment can affect change on our body and behavior.

I would say that behavior is embodied, embedded, enculturated, and enabling probably some other use, but at least there's data about it.

Paul Middlebrooks
You're referring to-- was it *The Annual Reviews in the Developmental Psychology*, maybe?

Karen Adolph
Yes.

Paul Middlebrooks
It's a really nice piece. I'll link to these things that we're talking about. Let's take them a drastic turn because I want to hear your thoughts about modern artificial intelligence and how it relates to the way that you think about cognition and natural intelligence. Because then I want to bring it back to design.

Karen Adolph
Yes, I think that at some point, someone had proposed the ultimate AI challenge, beating a grand chess master at chess, and then Deep Blue did it. When you watch it, it's hilarious because there's a computer and then there's a guy who is translating the moves to tell the computer where the pieces are, and then taking the computer's output and moving the pieces for the human player. All right, Kasparov lost the game, but the guy is moving his own freaking chess pieces around and knowing where people have moved his chess pieces. Deep Blue couldn't do any of that.

Then that challenge got replaced with a RoboCup challenge. True intelligence would be building robots that could be the best human World Cup champions or whatever. One of the originators and also one of the people who's been most successful at winning RoboCup and various simulated and real robot divisions is Peter Stone. I've very much been blessed to work with him and other roboticists, Alan Fern's group at Oregon State, and Lerrel Pinto at NYU. I think that-- sorry, what was your question? AI and mind? Something like that?

Paul Middlebrooks
Yes, just your take on AI and-- because of the disembodiment, right? What I really want to ask you-- what?

Karen Adolph
I think the most helpful part about computer science, in general, for behavioral scientists, neuroscientists, et cetera, cognitive scientists, is make your ideas explicit in some ways. Now, I think there's great power in metaphor and the most truly powerful theories in developmental science are all at the metaphor level, like PHAs. whatever, I mean it's wrong, but truly powerful. It's really helpful when you can boil it all down. That's my Carnegie Mellon background, coming out and put it in a formal model. Why not put it in a formal model in a real thing, like a robot? That's the ultimate formal model.

Now, real robots are not very good. They're really clunky. An 18-month-old human toddler can run circles around the best one of those. A robot and simulation has a lot to offer, behavioral scientists and neuroscientists at this point. Computer vision has a lot to offer. I think developmental science has a lot to offer to AI. One easy example back to the robots is that a human infant, for example, they learn so much so fast, I think in part because what they need to learn is constrained by their bodies and their bodies constrain their effective environment.

It's not a looming, buzzing confusion because most of the environment isn't impinging on them at all. It's like it doesn't exist because they don't have any access to it. They don't see it or hear it or whatever, so who cares? Whatever. Then as they get new behavioral skills, their environment expands. They're continually pushing their own skills and expansion of their own environment.

Think about like learning to walk. Literally, a baby can wake up and find themselves two centimeters taller than when they went to sleep. Their body is different. Yesterday, they couldn't stand up at all. Now they can sit. A week from now, they can take steps. That baby is never going to get

stuck learning any fixed fact at all. It's never going to learn, "I'm a crap walker. I'm a wonderful walker," because what he was yesterday isn't true anymore today. It's never going to learn, "Don't move this or don't step on the carpet because you'll fall," because turning his head made him fall. It doesn't--

The system is geared toward-- that's true for motor behaviors, was true for language, is true for social interaction. The system is geared toward flexible, generative, creative, learning. That would be a great lesson for AI. I think that some people in AI are hearing this, loud and clear, it's hard to implement right now in a robot, but totally doable in simulation. There's some really smart people out there that are really interested in these questions.

Paul Middlebrooks
In, for example, any organism, let's take humans, one could argue that those developmental changes that are happening that enable the context to change because the environmental access changes where baby can even position its head and look changes. It's growing and its coordination is changing. That could be a bug instead of a feature, right? It's a necessary thing just because we have to be born small, and our bodies go through these changes.

Karen Adolph
There's lots of things that could be bugs or they could be features. It's totally possible that all the animals in the animal kingdom and they all develop, this was a bug, but something that's just a by-product and you can gloss over it. You can test that and you can ask, "Is it actually a feature or a bug?" It turns out all the variability is absolutely a feature. That leads to better, faster learning, more generative learning, better transfer, everything, at least to winning more games in RoboCup.

Paul Middlebrooks
Is there something about development, specifically, that makes it a necessary way forward to that high amount of flexibility and rapid learning? Couldn't you just figure out the algorithms necessary for it and build it in a computer? I'm playing devil's advocate here.

Karen Adolph
I think you'd have to also structure the learning curriculum just right. Currently, with Peter Stone's lab and Alan Burns' lab, we're trying to do exactly that.

Paul Middlebrooks
In simulation?

Karen Adolph
Yes, they don't want to necessarily have a robot that develops, but if they could understand what the optimal curriculum is, then they could have their algorithms be exposed to the right environments at the right time so that the algorithms become as powerful as a human child. If they could do that-- Forget getting to our level, adult level, or whatever. You don't need wisdom. You just need a robot that's a two-year-old and then, man, that'd be amazing.

Paul Middlebrooks
You don't think that there is something special about the way our bodies change and the fact that we are embodied and it's always a relation between our body and the environment and affordances, I'll say [chuckles], that would be necessarily missing in a robot that wouldn't go through those changes because it's always had the same body?

Karen Adolph
You might need to change its body. I don't know. My diabolical scheme is to use simulated robots to understand behavior, but their diabolical scheme is to use developing behavior to build better robots. It might turn out we've got to have a robot whose body can change, and you can't do it all with meeting out the environment and adjusting the algorithms. That's their problem. They'll figure it out.

Paul Middlebrooks
Maybe. Maybe with your help. How much does embodiment matter once we're fully developed?

Karen Adolph
It always matters. It always matters.

Paul Middlebrooks
But how much is the-- because one could argue that it might matter more as we're developing because all of our cognition develops, as you've studied over many years, in congruence with our bodily changes and that--

Karen Adolph
My dear, you're in that happy point of life. I can tell you from the other side, we are always developing and our bodies are always developing.

Paul Middlebrooks
[chuckles] Oh, I know that.

Karen Adolph
Gravity might be your power right now, but gravity is not your long-term friend.

Paul Middlebrooks
No, I love watching the--

Karen Adolph
[chuckles] You know what I mean? No, seriously, we're always developing. Your body is always changing. Your body is changing when you put on your sneakers or take them off in your barefoot or in your socks. Your body is changing when you pick up your backpack. Your functional body is always changing because you're always doing things. Every plan you make, every action you take has to take the current status of your body into account. Even raising your arms changes your body and changes what you can do next.

You're always embodied and you actually are always developing. Development is different across the lifespan with which things grow and which things shrink or sag or whatever, but it's changing.

Paul Middlebrooks
I remember when I was younger and falling was actually fun. First of all, you'd be fine if you fell. I remember actually enjoying it. I used to fall on purpose to make my friends laugh because it was just hilarious. I don't look forward to falling anymore [chuckles], but this is one of the things that you studied, just how much developing infants and babies just fall and just get up and are fine, and they're just tumbling around the world, and enjoying it.

Karen Adolph
Maybe what you're referring to is the three to six-year-old period when children twirl in circles and stand in the snow drift or a leaf pile and--

Paul Middlebrooks
Oh, I used to be able to stand straight up and this was still when I was a teenager and just fall face forward on concrete and just put my hands out and be fine. Now, I'm not going to try that today.

[laughter]

Karen Adolph
No. I don't think that babies enjoy falling, and I don't think, in general, they're doing it to amuse anyone. I just think it's pretty trivial. It happens so often, and it's pretty trivial. When it's not trivial, they probably die, but that's a tiny proportion of the time.

Paul Middlebrooks
Right. Never in your lab.

Karen Adolph
Knock wood. Originally, years ago, I had parents keep a diary every time their babies fell, and it was 1.2 times a month. Then we put video cameras on babies and just videotaped how often they fall. A new walker-

Paul Middlebrooks
Like a thousand times a month.

Karen Adolph
-falls 35 times an hour or something like that. Babies fall 70-something times per hour in motion. Then we've microanalyzed the falls, and they truly are trivial. A baby on average is back at play-- from fully torso on the floor to up and running around again in under two seconds. Think about it like this. In the beginning, babies fall because their legs give out, which they're standing there and their legs collapse, or literally, they turn their head or lift an arm and it tips them off balance and they fall. Would you want a robot or a baby to learn, "Never turn your head. Never take a step. Never lift your arm." Of course not. They ignore it because it doesn't matter.

Paul Middlebrooks
Wait, who ignores what? Babies ignore falling?

Karen Adolph
Yes. If you have a robot ignore it, so there's zero penalty for falling. It learns better, faster, deeper, better transfer, et cetera. It's not just motor actions. If a baby learned that every time it said a word and mispronounced it, it would get a penalty, we would never learn to talk. If you said an ungrammatical utterance, you would never learn to talk. You just shut down the system. For things that really need to be highly generative, highly creative, highly flexible, you have to allow errors.

Paul Middlebrooks
What is your prospect about AI, in general? Do you think if only they added what we learn in development that we'll solve it? Do you think it's

something that is poorly defined in the first place because we use the term intelligence differently when we're talking about organisms versus computers, for example, or do you not think about it? I know you don't [crosstalk]. it's not what you study.

Karen Adolph
I try not to think about things like large language models.

Paul Middlebrooks
Why?

Karen Adolph
We've been testing-- I guess it's the right word-- using, testing automatic speech recognition tools like Whisper for transcription because human transcription takes a really long time. I'm talking not about newscaster transcription and against the background of quiet, but baby's vocalizations and mother's infant-directed speech or caregiver's infant-directed speech in noisily cluttery environments, and also with code-switching among languages, et cetera. Humans can do it beautifully, highly accurately.

Automatic speech recognition can sort of do it, sort of, so far. If you run the same exact algorithm multiple times, you'll get different answers over different runs. A lot of the answers involve huge amounts of hallucinations where it just makes up stuff that never happened. Part of it is that the input to most of the AI models for speech, for behavior, for computer vision, whatever, are scraped off the web, and it's not good input. I don't know if about the Databrary video library, but this is the world's only large-scale repository, digital repository for research video.

Paul Middlebrooks
This was started by your team, right?

Karen Adolph
Yes. This-- I don't know, I think there's 790 universities around the globe who are now authorized to access this. It's a controlled-access repository with open sharing within the users of the repository. Not for commercial purposes, not for some company to make money by learning your predilections and what the things are in your home, but for researchers, including AI researchers to have really good data. A lot of it is human-annotated or human-transcribed, so there's a lot of gold-standard data sets in Databrary.

I think things like that will help AI. I try not to think about the nefarious uses of AI, and I try to think more about, what I said to start, how AI can help behavioral scientists, including developmental scientists, to understand behavioral processes more deeply and more accurately.

Paul Middlebrooks
How has the modern technology, machine learning techniques, tracking techniques, changed or improved your research? You were just mentioning earlier that you used to ask people to just observe their children at home, right, and keep a little diary. Now, you have people bring their babies and kids in the lab. You can track their every movement and really quantify things, where they're looking. They can be wearing an EEG cap while they're doing some task. You can track their-- one of the things that you've done is how babies at different stages of development will make different errors in picking up a hammer that has different orientations. Wooden hammer, not a lethal hammer.

[laughs]

Has that been like-- I hate to use the phrase a game changer, but are you in the best place ever in terms of the tools that are available? Has it changed how you do your research?

Karen Adolph
I'm a great fan of technology, and because I'm in movement science, people in movement science have been using recording technologies forever, long before anyone in mainstream psychology or cognitive science and neuroscience had the ability or even realized it would be important to do.

Everyone trained as I was, one of the golden rules is you use technology to answer the questions you have. You're not led around by the technology. One of the things I'm most proud of is my lab with Jason Babcock developed the first-- so Jason Babcock is the owner of Positive Science, but we developed the first head-mounted eye tracker for infants and children while they're fully mobile. Babies, children can run around, do whatever, in their home, in the lab, walk over apparatuses, narrow bridges, whatever, all while wearing a head-mounted eye tracker that actually tracks their point of gaze in the scene. Not just like a-

Paul Middlebrooks
Let's just say it used to be a care [crosstalk].

Karen Adolph
-GoPro on their head, but actual eye tracking. Amazing. If I had to choose what I'd rather have, a head-mounted eye tracker on a baby or a third-person camera that gets the whole scene, I'd pick the third-person camera in a nanosecond. Head-mounted eye tracking tells you one thing, third-person camera really tells you another thing.

Paul Middlebrooks
My sense is that you're using it all. You're using so many tools at once.

Karen Adolph
Yes. I do a lot of things in combination. For a lot of the behaviors that I'm interested in, it's prohibitive, or at least it's not nice. It's not practical to put too much stuff on the baby. We try to have everything--Like instrument the floor rather than instrumenting the baby or use computer vision to track the baby's joint angles rather than putting markers on the baby or wires on the baby, et cetera. It's interesting.

For a human, it's absolutely trivial to know if a baby is taking steps. I'm not talking about babies stepping as if they're walking on a treadmill. I'm talking about babies taking their natural steps as they approach an obstacle or during play. The steps are in place or backward or they slither foot or-- every direction, windy paths, the whole thing. If I showed you a video right now, we could both, in unison, say step, step, not a step, step, step, step, not a step, like that. Really hard for machine learning to do that kind of a thing.

It's not up to the task. On the other hand, computer vision can tell you the exact XYZ coordinates of the feet. If the space is calibrated, a human can't do that. If I were wearing a head-mounted eye tracker, a human could say I'm looking at the wooden wall, but it can't say which pixels on the wall I'm actually looking at and which are out of my field of view. A human can say you took a step closer to this target, but it can't say exactly what are the XYZ coordinates.

It's like a happy marriage where you find the right technologies and the right tools, some of which are humans, and you can build tools to augment human abilities. One of the Databrary suite of tools is DataView, which is a human-computerized video annotation tool, where user-defined events, behaviors can be time-locked to their location in the video. You need stuff like that. If you don't have that tool, and you're writing it down with paper and pencil, it's just prohibitively expensive and horrible and not accurate enough to do.

It's a tool that gives you a perfect playback over the video, and you can go forward or backward at different speeds with fingertip control, and you never have to touch your mouse. That's an amazing tool. That augments our human abilities. That's how I feel about it. Technologies are amazing. I'm very proud of the work that has come out of my lab where we push technologies forward instead of just measuring babies walking in a straight line, which you have to force them to do, or using an instrumented floor to see what natural locomotion really looks like and what the gate parameters look like there.

I think it's very important that the neurosciences and behavioral sciences, developmental sciences are not getting led around by the promise or existence of certain tools.

Paul Middlebrooks
Am I right to say that looking time studies in babies was the gold standard for a long time? What I want to ask you is, is that over? Does anyone still do [crosstalk] time?

Karen Adolph
Unfortunately, and shamefully, it is long from over, not over. I think we need to be very clear what's a looking time study.

Paul Middlebrooks
Yes, thank you. That's what I was going to ask.

Karen Adolph
Looking is an incredibly beautiful, amazing, important motor behavior. Coming back to where we started, James Gibson pointed out that looking is not a behavior that is limited to just the eyes. It's the eyes and a moving head and a moving body. Anyone who doubts it, just watch your baby, your toddler out of the high chair, how he looks at things. They crouched in whatever. Looking time study started in the early 1970s with Robert Fantz when people have limited ways of studying babies. Some of the ways that people were studying babies are still really good ways to study babies using operant and classical conditioning. Operant conditioning is an amazing way to study a baby or any other animal.

You know why? Because you can make inferences about a single participant. That's why Skinner and a lot of his famous studies, B. F. Skinner only needed one pigeon or one rat, because you can say with 100% certainty that you have altered this animal's behavior, based on some reward structure. Fantz realized that you could show babies displays and measure how long they look at the display. That was originally used to ask whether infants could discriminate between different kinds of visual displays. That's a totally good question. The technologies they have for doing it were pretty limited.

It started with just an observer peering down at a baby lying on its back and the baby's looking at displays or has the opportunity to look at displays and the observer just pressed a button saying that the baby look at the left display or the display on the right or display on the left, like that. We're essentially doing the same thing in looking time studies. Only now, the questions aren't about discriminating visual displays, the questions are about cognition. If an infant looks longer at a display, it means that they were surprised, or the display was unexpected or whatever.

I think for normal people listening to this, when they hear that a baby's surprised, they think the baby's saying like, "Oh," or something's happening besides on average, a group of babies looked like that, a little bit longer at one display than another a few seconds longer. That's the data. Typically,

it's not even in terms of the portion of babies that look longer at the whatever display. I've done those studies. Everyone in infancy research has done those studies. Everyone knows that it all depends on what the display is, if you want babies to look at it. Huge file drawer problem.

I don't even know a way to get around it. If you're trying to design your experiment, you have to play around with what the displays should look like. Then finally you get displays that it seems like the babies are interested in and you test them like that. This is not eye-tracking. Eye tracking is a new technology that became widely available in the 2000s, and by 2010, any lab will be doing this. That's where you actually track where the baby is looking on the display. Not, did the baby look left or look right or look away, but we're on the display. Was the baby actually looking at the thing that you the adult researcher thought was the surprise? Now you could actually know.

I don't think there's any excuse for using old-fashioned looking time measures when if you want to hit your app measure to be based on where babies look, eye track them and find out where they look. Because you'll find really interesting things. There's a beautiful paper by Scott Johnson from, I think, 2004. We showed that, on average, babies look longer at a display where an object appears to be moving behind an occluder like that. Turns out some of the babies are, when you actually use eye tracking and get the location of their looks, some of the babies are tracking the moving object.

Some of the babies, though, are looking at the edges of the screen, or they're looking at the occluder. They don't they don't know how to guide their visual exploration. The babies that have learned more about how to plan their visual exploration, those babies also perform better, in the straight-up habituation task, but they also perform better in a whole range of other tasks. I just think like, why are we using a really weak tool, method, procedure, when we have all kinds of other things available to us?

Paul Middlebrooks
It's still quite prevalent?

Karen Adolph
It's quite prevalent. I would say it's probably the most common way to study infant cognition, and among the most widely looking time methods are among the most widely used methods in all of infancy research. There's just no excuse for it. If you want to know if the baby's surprised, you could also be looking at their facial expressions and gestures and vocalizations and dilation and lots of other things that are all there in the videos. People don't, out of laziness, and also because it often doesn't have anything to do with how long they're looking, which argues against it being a surprising event for the baby.

Paul Middlebrooks
I was telling you a little bit about my background. What I didn't say is that my PhD was in an eye movement/neurophysiology lab. Back in the old days, and this is non-human primate, and it's still done this way frequently as well, but you would do eye tracking, but you would want your experimental setup to be as controlled as possible. We would head fix the monkeys. They'd be sitting in a chair because we don't want their head moving because we want just their eyes moving so we can track it. Then first something, in my case, about the way that they were making decisions with their eyes. These days is very different. I'm working with a data set now. Naturalistic behavior is all the rage now. That's a lot what you do. You do do controlled experiments, but you also just measure a naturalistic baby child developmental behavior in the lab. You set up the lab to make it **[inaudible 00:57:33]** [crosstalk]

Karen Adolph
I want to come back to a discussion about naturalistic, natural, whatever unnatural setups, but I want to hear the rest of your story first.

Paul Middlebrooks
Where was I? Oh, what I'm doing now.

Karen Adolph
Primate eye movements.

Paul Middlebrooks
I don't do that anymore. That contrasts with these days naturalistic behavior has exploded. You want me to tell you my dissertation? Is that what you're asking?

Karen Adolph
I wanted to hear that. I didn't want to interrupt you and stuff like that.

Paul Middlebrooks
No, that's okay. These days I have, I have a challenge, a problem, a challenge. Let's go, optimistic. I came to this lab where I'm doing another postdoc, the Eric Yttri lab. We have these really high density, neural recordings and freely behaving mice. They're just walking around the cage or a box in my case, in my data set case, grooming, locomoting, investigating.

When you were talking about earlier, how you can watch a child and say, "Oh, that's a locomotion. That's a locomotion. That's a step. That's a locomotion." Already when I got to the lab, they had developed an unsupervised learning technique to basically use the kinematics data to categorize different behaviors. I have all these behavior labels. I have a bunch of neural data.

The question is, how is the brain enacting these behaviors? It's a wild west right now in neuroscience for naturalistic behavior, because we have all this data now, we have all these machine learning techniques, and the whole history of neuroscience, like my PhD experimental setup is just do the same thing over and over and over exactly the same way. Control that as much as possible.

Then you average all the same behaviors and compare them to some other behavioral condition. Then you say, "Oh, there's a difference, that must be how the brain is doing it." Now, we have a freely behaving mouse who sometimes grooms like this, sometimes like this, sometimes it walks a slightly different way. It slightly turns left. There are all these like minutiae of the behaviors. The neural activity is not nearly as clean, at least in the areas where I'm recording. This is actually where I wanted to bring up a piece that you, and I didn't know he was your partner, wrote about developing motor cortex. One of my pet little, it's not a theory because it's not strong enough to be a theory, but thoughts is that the areas that we're recording in, which are primary motor cortex and basal ganglia, probably aren't needed for these innate, naturalistic type behaviors, but because there's no motivation, there's no reward, there's no attention, there's nothing going on. I'm not sure--

Karen Adolph
I have to interrupt you because now you're getting annoying. [chuckles]

Paul Middlebrooks
Awesome. [chuckles]

Karen Adolph
Except for in the beginning of graduate school, where I learned to do looking time studies with babies strapped in a car seat, I've only done studies where the baby, the child, whatever, was free to just continuously do some kind of behaviors that were new to them, new to us, surprising to all. You mentioned our study of four or five-year-olds hammering a peg.

We saw children do things in hammering a peg that no one would ever have imagined that a child would do, 100 whatever, tiny little taps to hammer the peg down. Children using their chest and their bodies or whatever to turn the hammer handle the right way if they grasped it in an awkward position, coming like this to grasp it so they would end up in a radial grip when all they had to do is just do an under hand grip to get it in a radial position. In infants locomoting--

Once when my child was-- my child's grown but when my child was a child, we did a science day for their 6th grade class, and we just asked these 6th graders to crawl on a straight line down a carpet. We saw so many types of crawls. It was absolutely amazing, bunny hops and children who could crawl with aerial flight phases, with all four limbs in the air, like a horse, and they're only going a few yards.

That was a long-winded way that you'll have to edit down to say that, "I think it's very important that in any task, the animal, person, has enough room that they can respond in ways with behaviors that are new to them and new to you." Otherwise, why even do it? Because, you sucked all the life, blood, and the fun out of the enterprise.

Paul Middlebrooks
I'll just interrupt you there and tell you why the history of neuroscience has done it.

Karen Adolph
I know why they've done it, but really? You don't need to do it to have sufficient control. I generally use psychophysics. Psychophysics and operant conditioning are the two ways where you get the most strong data from a single participant, so where your inference is about what that participant is doing or knowing or perceiving or whatever are most powerful, and you don't have to rely on group averages.

Naturalistic to me is like putting a freely moving mouse in a cage, or Rob Froemke's lab at NYU, does these beautiful studies of mouse DMs over consecutive births of their litters and caring for the pops and so on.

Paul Middlebrooks
You said mouse what's over the consecutive?

Karen Adolph
Litters. Giving birth to a litter of pups and then leaving the pups and managing the nest, and then they have their second. It's 24/7 mouse recordings. They're in a cage. I guess I would call that naturalistic. I do similar kinds of things because we want to sometimes have studies where everybody has the same environment with the same objects and the same recording setup, or it's a highly calibrated space that's a really conducive to computer vision, et cetera.

I also do natural behavior where you just go out in the wild with your video camera, and it's just people doing what they do, the end. It's not -istic anything. It's just actual natural behavior. I think that whole continuum is extremely useful from a pretty controlled experiment where you want to do something like psychophysics or operant conditioning but where the animal still has freedom to do its thing to truly natural behavior and somewhere in the middle is the so-called naturalistic, where it's a little bit like life, it's whatever.

Paul Middlebrooks
What was the annoying part? Just the usage of the term naturalistic? Which is totally staying in, by the way. [crosstalk]

Karen Adolph
Oh, you were saying that naturalistic behaviors are innate behaviors.

Paul Middlebrooks
Oh, no, I didn't mean to conflate the two, but what I meant by innate, so naturalistic is just in this sense just the mouse being able to just wander around on its own accord at its own timing, but the behaviors that it's enacting are innate behaviors, it knows how to groom. It's not performing any task. Maybe it learned how to groom better [crosstalk]

Karen Adolph
Innate is the wrong word, it's not a prescribed task, an externally directed task. It's just the mouse doing what it wants to do. Do mice learn to groom? Yes, they do.

Paul Middlebrooks
I'm not going to argue with that.

Karen Adolph
There's a whole range of experiences that mice have to have for them to be effective at learning when they need to groom themselves.

Paul Middlebrooks
We need a single term for naturalistic, non-innate, at some point learned, but non-task related behavior, perhaps.

Karen Adolph
Yes, that would be good. That would be fine.

Paul Middlebrooks
We'll come up with something. Anyway, the data is not perfectly aligned to anything. Our unsupervised learning algorithm says at some time temporal scale like when locomotion started, but this locomotion might have begun with left paw moving forward for us, the other one with the right paw. We're doing the thing where we're aligning, like traditional neuroscience, aligning the beginnings of a behavior to a specific time point, but the behaviors are enacted somewhat differently, algorithm isn't perfect, et cetera.

We have all this data. It's fairly aligned, but there's a lot of variation in it. It's been a challenge to relate the neural activity to the different, in this case, we have 16 different behavioral categories. Relate the neural activity to those behaviors, and one reason may be that cortex is maybe not the major player, maybe not needed except when it is. When I came across the opinion piece that you and your partner wrote, or the perspective maybe, about how early in development motor cortex is not motor, it's more sensory.

Depending on the organism, it takes longer or shorter for motor cortex activity to be able to even direct behaviors because the connections literally aren't there when it's younger, but it is giving sensory information. I just thought that was interesting, and I'm not sure if I'll present your perspective in my lab group, because there's a lot of talk about like, "Motor cortex must be doing these, so how is it doing it?" Maybe it's not doing it.

Go ahead. Am I getting annoying again?

Karen Adolph
No, not at all. Adults across the lifespan, we do lots of movements that don't require cortex to control them. The argument in that perspective piece is essentially that there is no connections. The things that the researcher's using to make inferences about what's happening in the baby's mind are not coming through cortex. If you want to say that whatever month old, a 7-month-old or 15-month-old has moral reasoning-- 3-month-old has moral reasoning, yes, but it's not the same moral reasoning as an adult would have. It's like, what is it? That's just sloppy science. Let me get Mark and he can-- He's asking about the motor cortex thing and it's in the context of, in his own work, they're studying freely moving mice behavior in a cage.

Paul Middlebrooks
What I wanted to ask about is, so I have recordings in primary motor cortex and basal ganglia, and I had been thinking this for a while now that maybe for these less task, less motivated, less cortically necessarily driven behaviors, that it's mostly subcortical, whereas the motor cortex, you guys write about how before motor cortex develops, the necessary connections to enact skeletal motor behavior, it's actually getting sensory signals. That would make sense if motor cortex and/or basal ganglia weren't really that important for these behaviors, it would be sloshing around, sometimes delayed a little bit.

My thought is like, "What a cortex would benefit by being in the right range in case it needs to be called on?" It might not necessarily need to just be these beautiful tuning curves of neural activity aligned to the behaviors. I just wondered what you think about that, but also I just wanted you to explain a little bit more about that. Then you got some pushback on the perspective, right?

Mark: [inaudible 01:12:05]

Paul Middlebrooks
Published pushback, anyway.

Mark: Yes. There's a lot to unpack here obviously, because there has been relatively less work done on brainstem circuits, relative to cortical circuits and the direction of behavior. We don't understand fully the relationship between all those things, how they develop, how they are processed in real-time, how they lead to the types of time-sharing that you see in your behavioral repertoires where they're going from one behavior to another, which is a really complex process. And because mice being mice, everything happens very quickly. There are questions about how automatic a lot of these things actually are.

There's a developing literature in adults about how to learn behavior. Motor cortex is more involved in adult behavior, that the motor cortex is involved in that process. If you lesion the motor cortex prior to learning, you prevent learning. After a certain task has been learned, now you destroy motor cortex, and there's no effect on the learned response, which suggests that there's been an offloading of that behavior onto another structure not too different from what you might think about systems consolidation of memory where you pass. All of these things are controversial, and they all have to be taken, of course, with some grain of salt.

You also asked that about motor cortex being sensory early in development, both evolutionarily and developmentally. The motor cortex is a relatively late-evolving structure. You see a lot of overlap in those circuits in certain types of marsupials, for example. The motor cortex is not distinct from sensory cortex in a lot of species. Then what gives credence to that, I think, is when you look developmentally, when you see the motor cortex has initially a current sensory structure. My work happens to be involved with looking at how sleep-related motor activity reveals that sensory process.

It's also known that motor cortex in adults is receiving sensory input. There's a nice review by Nick Hatsopoulos in *Neuron* around seven years ago, called *Sensing with Motor Cortex*, which doesn't take any developmental perspective at all and still talks about the role the motor cortex plays in processing sensory input. It's a lifelong process, and it makes sense because motor cortex needs to integrate input up from proprioceptors and other sorts of peripheral information, and then use that to structure a lot of the--

Karen Adolph
Can you give the argument in the two papers? The basic argument, and then I don't know if we need to talk about pushback. At least give the basic argument so Paul can edit out whenever he wants.

Mark: The basic argument is that I got to report **[inaudible 01:15:11]** [crosstalk]

Karen Adolph
I got to agree that, too. We should have that picture. There's the behaviors, we're using those to make inferences about cognition **[inaudible 01:15:21]** [crosstalk]

Mark: Let's start with the developmental picture is that motor cortex, like a lot of other structures like cerebellum, it's a very late developing structure. You can see this. There's some evidence from the human literature, for example, people with cerebral palsy, where it's mostly caused by a perinatal stroke. That's one of the more predominant causes of cerebral palsy. The symptoms don't show themselves until four, six later months after birth. Why would that be if motor cortex is so? We all know that if you have a stroke when you're an adult, you have immediate paralysis that doesn't show up in **[unintelligible 01:15:58]**

Also if we look from cats, rats, developmentally, you see that motor cortex is not-- All the evidence that we have suggests that motor cortex is not developing for weeks in the case of rats until after weaning. You work with mice, if you look at mouse behavior around the time of weaning, it's pretty complicated. They're moving around the cage, they're drinking, they're eating, they're grooming. The evidence would suggest that all that behavior is brainstem dominant. I said cats, and a cat's showing up.

Paul Middlebrooks
That's a dog. It's my dog.

Mark: [unintelligible 01:16:39] Where was I?

Karen Adolph
Bring it to the developmental **[inaudible 01:16:48]** [crosstalk]

Mark: No, I understand. The point is that in mice, you're seeing complex behaviors when motor cortex is not involved. I think that has relevance to the work that you're doing. The best evidence or one of the best pieces of evidence that you have for demonstrating motor cortex involvement is electrical stimulation of the cortex. You don't see movement of the limbs in rats until 25 days after birth, which is extraordinary. Now that doesn't mean circuits are-- You cannot bring those circuits in to produce behavior. It's just that without a lot of manipulation of those circuits, you don't see evidence of movement. That's pretty strong evidence.

If you take that, then you go back to the human literature, and all of the things that are being put into the minds of babies, which, whether stated or unstated, whether implicit or explicit, people think of as cortically acquired cognitive processes, then the clear inference would be that a lot of

these behaviors either are not being controlled by the cortex or some of these statements, some of these experiments are either not well done or they're based upon flimsy research or flimsy methods or what have you, and there are incorrect inferences being drawn about what's happening.

Karen Adolph
Either way. In the best case, assuming the data are real and reliable, not motor cortex driving those looking times, not motor cortex driving the neonatal imitation, not motor cortex driving the behaviors. That means that it's not the seeing underlying representations as in an adult.

Paul Middlebrooks
At some point, motor cortex got the name motor cortex. What does this say about how naming something affects the way that we assign function to it?

Mark: Naming things, I think science is filled with problems with that. You could make the same arguments about genes. You have a gene, you call it sleepless because a mutant mouse **[unintelligible 01:19:17]** happens to not sleep. Obviously, these things are not doing just those things that **[unintelligible 01:19:25]** Motor cortex has that name, but it also does a lot of sensory processing. Yes, it's a problem for how we name things. It's yet another example of how our names get in the way.

Paul Middlebrooks
Yes, because you name something, it reifies it for sure.

Mark: Absolutely.

Paul Middlebrooks
Let me just ask you, Karen, one more thing. Thanks for, I guess--

Karen Adolph
Zoom bombing our podcast.

Mark: No, I was going to say thank you for solidifying my thought about why I'm studying something that doesn't exist. That's terrible. It'll get there. I'll publish something because I have to publish something. What I want to ask you about, Karen, is what you're excited about these days. I know you just submitted 15 grants or something. I think it was four grants that you're you'll be submitting in August, I think you said and so you're going to continue to be prolific and busy. Anything that is particularly exciting and/or challenging?

Karen Adolph
I don't know if I can prioritize. I just have to tell you the things that I think are super exciting. One thing that's really exciting is collecting corpora of what people's natural behaviors really are. We have done that out the wazoo for families in New York City. We're also doing it with the help of 73 PIs across the US and Canada for infants and their caregivers across 35 sites in the US and now we're taking it global. Imagine you or any researcher being able to access Databrary and see what life is like for babies and their caregivers anywhere in the world during not naturalistic, natural, we call it-- The acronym is BABIES, B-A-B-I-E-S. And it stands for Babies Activities and Behaviors In Everyday Settings behavior **[unintelligible 01:21:47]**

Paul Middlebrooks
Because I don't know how hard you've worked on that acronym, but great.

Karen Adolph
I know. Good work, Karen.

Paul Middlebrooks
Good work.

Karen Adolph
That's something that I'm really excited about and something that would only be possible with a resource and a platform and a tool like Databrary. I guess the honest answer, though, of what I'm really, really excited about are the same things that have excited me since I was a graduate student with Eleanor Gibson. I want to know how babies learn to guide their actions from eyes to toes in an adaptive and functional way to do the things that they need to do and the things they want to do.

Paul Middlebrooks
How long is it going to take you to figure out? Five more years?

Karen Adolph
I'm old, so I figure I'm giving myself 10 years to do it. Currently, one way we're doing that, is same babies, we study them solving these problems on apparatuses, deciding how high of a drop-off they can walk over, how steep of a slope they can walk up or walk down, et cetera.

Then the same babies, we also observe naturalistically in our laboratory playroom where we can see how much they move and how they move and whatever while they're playing alone and while they're playing with their caregiver, and the same babies doing totally natural behavior in their homes for one hour, concerted activity between naps and meals, et cetera. Then also using video ecological momentary assessment where the caregivers take little 10-second videos throughout the day over the course of a week.

Then we have standard measures of walking skill, natural walking, body dimensions, the whole enchilada. We'll study that. We're also now going to turn that into something where we can ask it in terms of simulated robot learning curricula. Then there, you can redo the baby's lives. Does it really matter if a baby steps on 179 different surfaces in the course of an hour? Maybe, but maybe it doesn't really matter for perceiving affordances.

Does it really matter if a baby has experience on elevations for being able to cope with, navigate, perceive affordances of elevations, novel elevations in the lab, maybe, but maybe it doesn't. We can address those things with simulated robots. Your question, does it matter that the body is changing? Does that aspect of embodiment really matter? We've tracked babies longitudinally, from two months to about 20 months in the same lab room, where at first they just lie on their back and stare at the ceiling, and by the end, they're running and touching everything in the room and using computer vision so that we know everything that was in their field of view and how that changed, everything they touched with their hands in the exact location and exact durations, everywhere their body went.

I think those kinds of approaches, it's big data, but it's also deep data. I think that's the way to do it. I think we got to put a lot of different minds on it. If I were all alone, I'd be looking at my videos with the sound off. Luckily, I have Catherine Tamis-Lemonda, the world's best collaborator, who's an expert in language and social interaction. I think if I were limited to what I could study solely on my own, I'd be looking at babies in New York City, living in apartments rather than out in West Lafayette, Indiana or whatever with my collaborator. We'd all be studying babies that live in things we recognize as a home and not in things that we go like, "Really, that's what a home looks like?" Another place in the world.

I guess that's a long way to say, let me say, you need to do the whole enchilada, Paul. You need to have the controlled experiments, they're highly enough controlled so that you can actually do something like psychophysics and say something definitive about each baby and each session, each participant in each session, just like visual psychophysics. Where they're free to do things that will surprise you and horrify you and delight you. Same with them.

You need to know what is the actual learning input, which things matter, which things might not matter, and how that changes with development. We actually right now, we as a field, because if Karen Adolph can do it, anyone can do it. We have all the tools and technology to do the whole enchilada. What my colleagues are still doing babies in a car seat, looking at computer displays and taking group averages, grow up, get a life. We have the technology, like the $6 million man. We have the tools and technology to do it.

Paul Middlebrooks
Will you do me a favor, in 10 years, you've figured this all out? Will you title the, oh my gosh, I think-- Is my microphone working? Can you hear me? Will you title the paper, The Whole Enchilada?

Karen Adolph
You got it, baby.

Paul Middlebrooks
Yes. It's a great phrase that doesn't get used enough anymore. Karen, thank you so much for your time. Tell Mark I said thank you for coming in. That was a surprise and it was fun.

Karen Adolph
All right.

Paul Middlebrooks
Brain Inspired is powered by *The Transmitter*, an online publication that aims to deliver useful information, insights, and tools to build bridges across neuroscience and advanced research. Visit thetransmitter.org to explore the latest neuroscience news and perspectives written by journalists and scientists. If you value *Brain Inspired*, support it through Patreon. To access full-length episodes, join our Discord community, and even influence who I invite to the podcast. Go to braininspired.co to learn more. The music you're hearing is *Little Wing* performed by Kyle Donovan. Thank you for your support. See you next time.

[music]
